Hierarchical Cell Deployment for High Speed Data CDMA Systems

Sangbum Kim, Daehyoung Hong and Jaeweon Cho
Dept. of Electronic Engineering, Sogang University
C.P.O. Box 1142, Seoul, 100-611, Korea
E-mail: hi_bum@sogang.ac.kr, dhong@sogang.ac.kr and jaeweon.cho@ieee.org

Abstract – **This paper presents hierarchical cell deployment strategies for high-speed data CDMA systems. Hierarchical cell structure has been considered as a method to improve the quality of service and increase the system capacity. We evaluate the performance of the hierarchical system with one embedded micro-cell. We show that the system capacity is dependent on the location of micro-cell site and its transmission power. Then, two different deployment strategies for hierarchical systems with multiple micro-cells are proposed and compared. The analysis results show that the cell throughput can be maximized by co-locating micro and macro-cell site with different frequency band. On the other hand, it is shown that both the fairness of QoS and the cell throughput is improved by deploying micro-cell at the edges of macro-cell.**

I. INTRODUCTION

The demand for the high-speed multimedia services has grown rapidly in mobile communication systems. High-speed data CDMA systems such as High Data Rate (HDR) of 3GPP2 and High-Speed Downlink Packet Access (HSDPA) of 3GPP has been proposed for high capacity/high speed data and the Internet access. IS-95/cdma2000 1X allow users to access voice or low data services. On the other hand, HDR and HSDPA systems can provide the high rate data services up to 2.4Mbps and 10Mbps, respectively.

One of the main features of HDR system is a time-division multiplexing (TDM) on forward link [1, 2]. On the forward link, access point (AP) transmits data to one access terminal (AT) at a time. The pilot, media access control (MAC) and traffic channels are time-multiplexed. TDM can suppress most of the intra-cell interference. All APs transmit the pilot channel at the same time. Therefore, the inter-cell interference could disappear if no data is transmitted in neighboring cell.

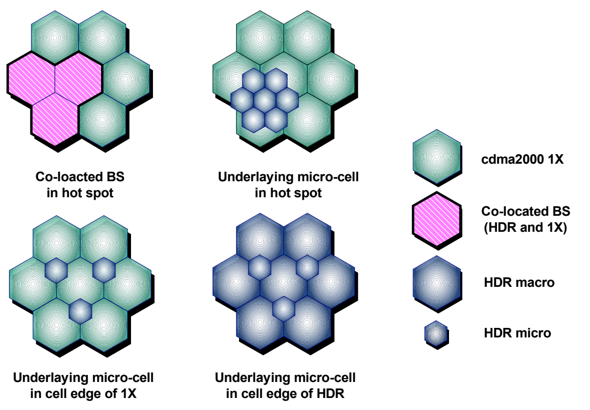


Fig. 1. Cell deployment strategies of the high-speed data systems.

It is expected that high-speed data systems should be deployed with the conventional CDMA system rather than stand-alone. High-speed data systems can be inserted into the hot spot and deployed hierarchically. However, the hierarchical cell deployment scenarios may be diverse and complex. The performance analysis of the hierarchical systems needs to elaborate the suitable cell deployment strategy. Examples of the cell deployment strategies are shown in Fig. 1. High-speed data system can be overlaid in conventional CDMA system or by itself.

This paper evaluates the hierarchical system performance in high-speed data CDMA networks and then develops cell deployment strategies. We concentrate on the performance of the forward link. System model is set in Section II. The system throughput is evaluated in Section III. Finally, we draw conclusions in Section IV.

II. SYSTEM MODEL

We have selected the HDR system as a high-speed data system model. For simplicity, we consider a homogeneous multi-layer system model consisting of HDR systems. AT is connected to AP with the highest C/I. After measuring C/I, AT determines the data rate that can be supported by the C/I. Since the entire power of AP is allocated to one user at any instant, the intra-cell interference by other users in the same cell does not exist. All APs always transmit the pilot channel and MAC control channel at the same time. The inter-cell interference caused by the overhead channels can be neglected because traffic channels are multiplexed with them in time division manner.

The AT may receive the interference signal from adjacent frequency band. As the spacing between the frequencies becomes wider, the attenuation level of the interference increases. Considering the interference from the adjacent frequency band, the received C/I can be represented as

$$\frac{C}{I} = \frac{C}{I_{OC} + I_{NC} \cdot \Lambda + N_0 W}, \qquad (1)$$

where I_{OC} is the inter-cell interference, I_{NC} is the inter-frequency interference, Λ is the level of attenuation and $N_0 W$ is the thermal noise power.

The cellular network is modeled by locating base station on the center of hexagonal grid pattern. The simulation model consists of 37 cells of 3 tiers. An omni-directional antenna pattern is used. The center frequency for the first frequency allocation is 880MHz, and the second center frequency is

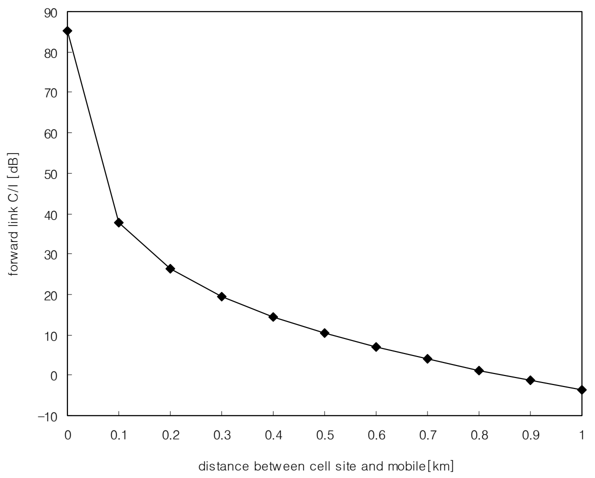


Fig. 2. The C/I of the high-speed data system Forward link, the Tx power of AP = 20W.

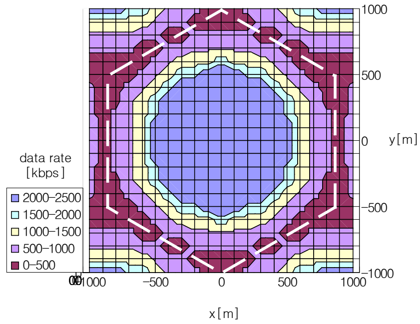


Fig. 3. The distribution of data rate for high-speed data system.

spaced out 1.23MHz from 880MHz. We use the modified Lee model for path loss.

III. PERFORMANCE ANALYSIS OF HIERARCHICAL SYSTEM

A. Forward link performance of high-speed data systems

The received C/I on the forward link is derived and presented. Fig. 2 shows the received C/I ratio at various locations. The radius of a cell is set to 1km and the loading of the neighbor cell is assumed to be full. Compared with the conventional CDMA systems, the absence of intra-cell interference in high-speed data systems enhances the C/I. However, the C/I at the edge of the cell can not be improved because it is mainly influenced by inter-cell interference rather than intra-cell interference. Since the C/I of 10dB can provide the maximum data rate 2.4Mbps [5], the higher C/I than 10dB is not needed. To eliminate the inter-cell interference, the AP ought to limit the transmit power for the AT close to the cell site.

After measuring the C/I, the data rate can be determined by the look-up table [5]. The geographical distribution of available data rate in a cell is shown in Fig. 3. The cell throughput is defined as the average data rate. The average data rate R_{avg} is defined as

$$R_{avg} \equiv \sum_i \frac{A_{R_i}}{A_S} \times R_i \ , \qquad (2)$$

where A_{R_i} is the area with data rate R_i, and A_S is the service area of a cell. The cell throughput in Fig. 3 is computed 1.44Mbps.

The assigned data rate is different according to the location of AT. Peak data rate 2.4Mbps can be assigned to the AT close to cell site. At the edge of cell, the data rate is given by 153.6kbps. To provide a fair quality of service (QoS) over the whole service area, the AP must assign longer transmission period to the AT at the cell edge. However, this can reduce the system capacity. One way to provide a fair QoS and avoid the decrement of the system capacity is the micro-cell solution. The micro-cell can serve the AT with higher data rate at the edge of macro-cell.

B. One micro-cell in the high-speed data system

We analyze the performance of the high-speed data system with an embedded micro-cell. In this analysis, macro and micro-cell use the same frequency band (FA). Fig. 4 shows the geographical distribution of C/I in the hierarchical high-speed data system. The micro-cell transmission power is set to 10W, the distance between the macro-cell and the micro-cell is 0.6km. We can see that C/I is improved near coverage boundary of macro-cell by introducing micro-cell.

The distribution of data rate in the hierarchical high-speed data system is shown in Fig. 5. At the inside-boundary of macro-cell produced by the embedded micro-cell, the data rate is decreased due to the inter-cell interference. However, the data rate is increased near micro-cell AP.

Fig. 6 shows the cell throughput of the macro and micro-cell with various locations of the micro-cell. The additional inter-cell interference caused by micro-cell reduces the average data rate of the overlaying macro-cell. However, total throughput of macro and micro-cell is much higher than that

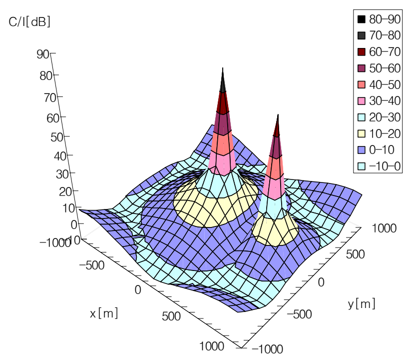


Fig. 4. The C/I distribution in the hierarchical high-speed data system.

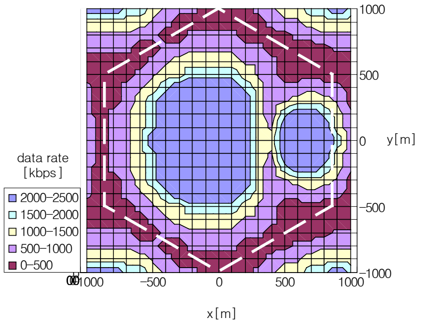


Fig. 5. The distribution of data rate in the hierarchical high-speed data system.

of macro-cell without micro-cell. As micro-cell site is kept away from macro-cell site, the total throughput of macro and micro-cell is increased.

Fig. 7 shows the cell throughput of the macro and micro-cell with various transmission power of the micro-cell. The micro-cell throughput is increased with its transmission power. On the other hand, the macro-cell throughput is decreased due to the higher inter-cell interference. The results show that, however, the total throughput of the macro- and micro-cell is not affected so much by the transmission power of the micro-cell.

C. Hierarchical cell deployment strategy

We now develop the hierarchical cell deployment strategies of high-speed data system.

Following two cell deployment strategies are compared. One is to deploy micro-cells at the edges of macro-cells, i.e. strategy 1. This strategy can improve the performance of ATs located near the coverage boundaries. The other is to co-locate multi-layer system cell sites, i.e. strategy 2. Examples of both deployment strategies are shown in Fig. 8. Fig. 9 shows the distribution of data rate of strategy 1. The same FA is allocated to both macro and micro-cell. We can see that the data rate at the cell edge can be improved by deploying micro-cell.

Fig. 10 shows the cell throughput with each cell deployment strategies. In strategy 2, transmission (Tx) power of all co-located APs set to 20W. In the case of the same FA allocation to macro and micro-cell, the throughput with strategy 2 is the lowest due to the extremely high interference between co-located macro-cells and micro-cells. With strategy 1, the macro-cell throughput decreases as the Tx power of micro-cell increases. The throughput with different FA is higher than that with the same FA, as expected. It is shown that strategy 2 with different FA outperforms the others in terms of the cell throughput.

The distributions with strategy 1 and 2 are compared in fig. 11. The different FA is allocated to macro and micro-cell. With strategy 1, high data rate is provided at the cell edge by micro-cell. Therefore, the high data rate area is extended by

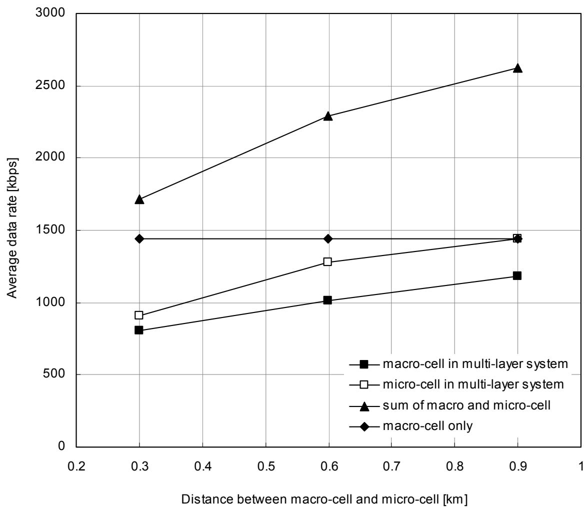


Fig. 6. The average data rate of macro/micro-cell with various locations of micro-cell.

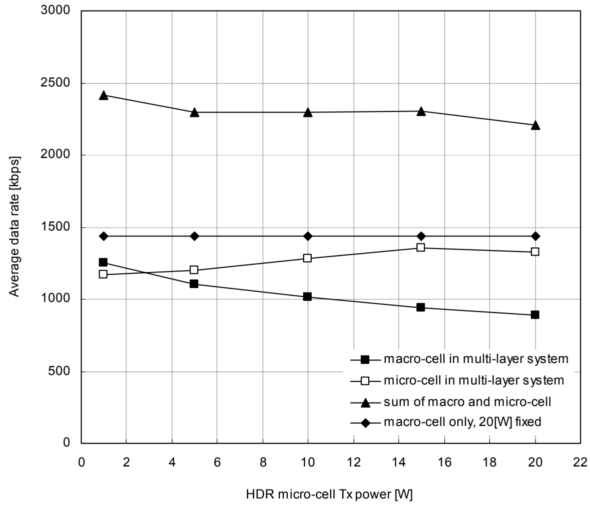


Fig. 7. The average data rate of macro/micro-cell cell with various Tx power of micro-cell.

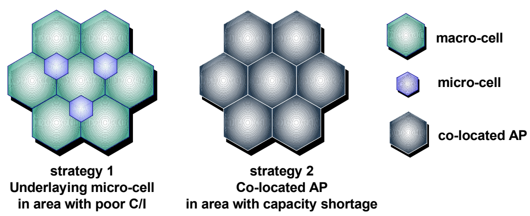


Fig. 8. The hierarchical cell deployment strategies.

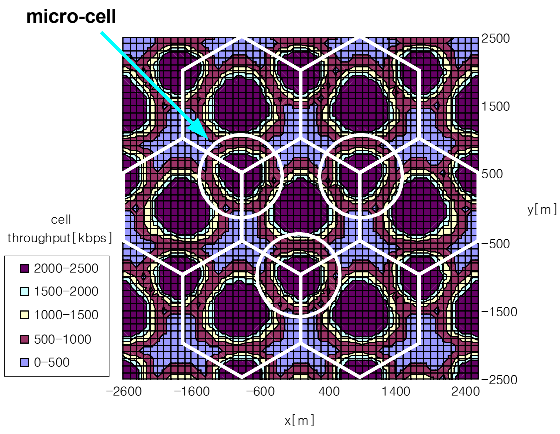


Fig. 9. The distribution of data rate : strategy 1 with same FA.

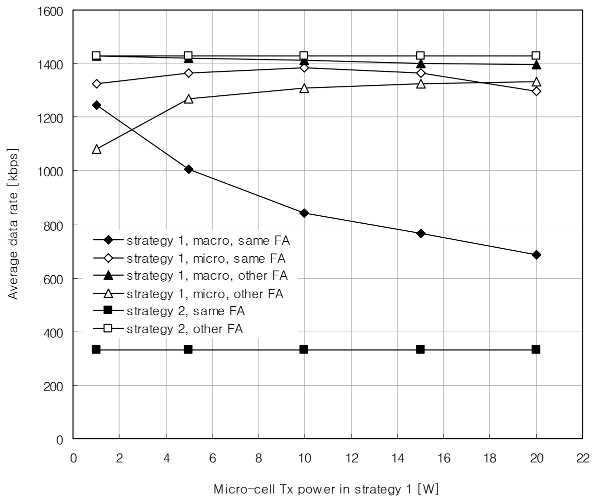


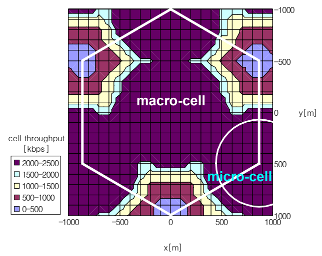
Fig. 10. The average data rate for strategy1 and strategy 2.

strategy 1. Although the overall cell throughput with strategy 1 is lower than that with strategy 2, the local cell throughput at the edge can be improved by strategy 1.

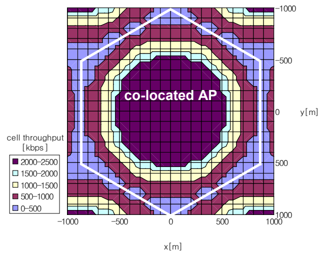
IV. Conclusion

We have analyzed a hierarchical system in high-speed data CDMA network. The forward link throughput has been evaluated in the HDR system model. Based on analysis results, the hierarchical cell deployment strategies that can enhance the system capacity have been presented.

We evaluate the performance of the system with one embedded micro-cell. The system capacity is influenced by the additional interference from the embedded micro-cell. However, it is shown that the overall capacity can increase by embedding the micro-cell into the macro-cell. Results show that the cell throughput increase as the micro-cell is located further away from macro-cell site.



(a) Strategy 1



(b) Strategy 2

Fig. 11. The distribution of the data rate in service area with different FA.

The cell deployment strategies of hierarchical system with multiple micro-cells are presented. Throughputs of the macro-cell and the micro-cell are derived and compared with each strategy. The results show that the cell throughput can be maximized by co-locating micro and macro-cell site with different frequency band. On the other hand, it is shown that both the fairness of QoS and the cell throughput is improved by deploying micro-cell at the edges of macro-cell.

The analysis results in this paper can be utilized for planning of high-speed data CDMA networks.

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